Comparison of remote sensing technologies of global the Earth's climate changes

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Abstract. – Major techniques of Earth's climate global changes control have been analyzed. They include: the techniques of surface temperature measurements and palaeoclimate records study, satellite climatology and global Earth's albedo measurement technique based upon earthshine observations. It has been shown that lack of specific measurement results in insuperable difficulties in discovering the cases and explaining the causes of the climate global changes. Proposals for the improvement of Earth's climate global changes monitoring techniques and their joint application have been formulated.

Keywords: global changes, climate, earthshine, radiation, albedo.

1. INTRODUCTION

The problem of Earth's climate global changes was raised in the sixties of the last century. First, only surface air temperature data of ground weather station net were used for the problem solution. Then, satellite measurements were used as well. Development of important satellite technique played also a small negative role causing considerable reduction of ground weather station net. Interest to Earth's temperature history stimulated development of the technique of palaeoclimate records study of the climate in the past. In the end of the nineties of the XX-th century the climate change control technique based upon earthshine observations was used again. Comparative analysis of Earth's climate global change monitoring techniques enables one to make up a conclusion about validity of using the near-surface air temperature measurements provided by existing weather station net, data of satellite and radiosonde probing for climate global change control, and find out usefulness of eartshine observations for the climate control.

2. THE TECHNIQUES OF CLIMATE GLOBAL CHANGE MONITORING

2.1 The near-surface air temperature measurement technique

The analysis of the measurements made by weather station net is routinely performed by different groups of scientists [Jones, 1994, Hansen et. al., 1999, Peterson et. al., 1997, IPCC, 2001]. This analysis has a whole series of limitations. First, the existing net consisting of ground meteorological (~7000) and radiosonde (~1700) stations does not cover oceans and is distributed over land surface non-uniformly. It is illustrated in Fig. 1a, that presents the bar chart of distribution of meteorological station number on 20 equal-area regions (~25500000 km^2), made by partition of the globe surface by regular icosahedron facets.

Symbolic notations of regions are plotted on the X-axis. Regions "10" and "11" with the largest numbers of stations (>1100) relate to North America and include a part of Great Britain. Regions "30", "40" and "41" with the numbers of stations varying from 450 to 800 include Europe, Russia, China, India, North and Central Africa. Finally, three more regions "33", "42" and "43", where Japan, Australia and Oceania are situated, have numbers of stations of about 400, with an average density of 1 station per 64000 km^2. Nine out of 20 regions, covering South Atlantic, the Pacific and Indian Oceans include from 15 to 139 stations. The non-uniform station distribution results in the fact that, for any instant, actually weighted average temperature is calculated instead of mean global

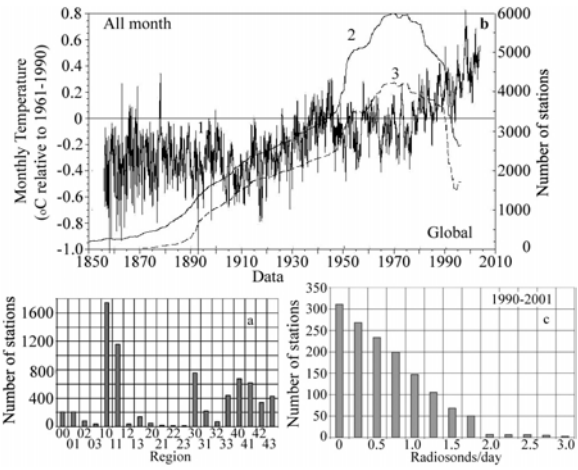

Figure 1. Distribution (a) of meteorological station number on regions, comparison (b) of annual temperature anomaly dependence (1) with station number (2 and 3) according to data [Peterson, et. al., 1997], and distribution of station number (c) on daily radiosonde launch number.

temperature. The presence of inhomogeneous weighting function in it misrepresents a sampling and makes questionable the use of the weighted average temperature instead of mean global temperature. Data in Fig. 1b show the time dependence of temperature anomaly and station numbers for average, maximal and minimal temperatures, and show correlation of the temperature anomalies with periods of change of station number. This fact also indicates possible influence of the sampling method used in statistical analysis upon final result.

Second, though [Peterson et. al., 1997] and [Hansen et. al. 1999] mention repeatedly the existence of more than 100 methods of daily mean temperature calculations leading to different monthly temperatures, they were never discussed it in detail. Let us consider this problem taking as an example the radiosonde stations chosen by us as the regular net. The bar chart of station number integral distribution on radiosonde daily launch number is shown in Fig. 1c. Daily, more than 1 launch is made only by every second station out of ~300 stations. Only 7 stations launch more than two radiosondes every day. Only 3 stations daily launch more than three radiosondes. It is evident that when such station net is applied it is impossible to make reliable daily temperature dependence calculations. The results of calculations of the function of Earth's surface irradiation by the Sun have shown that even for the simplest type of the irradiation function (1-2 harmonics), it must be verified, and hence the daily variations must be verified as well, not less than at 3 - 5 points. The explanation of distortions of the average annual temperature trends due to incorrect accounting of the daily dependence has been illustrated using the data for stations with WMO indexes 16560 and 88889. First, the surface temperature annual dependence has been approximated by 4 first Fourier harmonics. In contrast to ordinary arithmetical averaging, such approximation of the annual dependence decreases the variance of annual temperature. Moreover, the differences between experimental and theoretical values enable one to determine the daily temperature anomalies. The weight function for calculation of the daily dependence has been determined for the period of years 1990-2001. Since the year 1995 the function becomes not homogeneous. The immediate cause of it is the reduction in number of annual launched radiosondes (from ~1200 during the period of years 1990-1995 till ~750 in the subsequent years). The reduction was mainly performed by the decrease of daily radiosonde launches. Thus, the daily temperature averaging, similar to global temperature determination, has been actually performed with the non-uniform weight function distorting the final result. The coefficients of linear trends of average annual temperatures T_1 and T_2, calculated for stations 16560 and 88889 with ordinary arithmetical averaging and with the use of approximating representation correspondingly, have been determined taking into account all the daily measurements, only the extremal temperature values, and the remainder daily values. Slope values of trends T_1 (^{o}C/year) are equal (-0.006, 0.098, -0.043) for station 16560 and (0.017, 0.032, 0.022 ^{o}C/year) for station 88889. Slope values of T_2 trends are equal (-0.006, -0.004, 0.300) and (0.002, 0.085, -0.001).

2.2 Paleoclimatic measurement technique

The major sources of paleoclimatic information are dendrochronological data, coral geochemical reconstruction data, glacial core investigation data, results of analysis of cave, lacustrine and oceanic sediments, borehole temperature chronology measurements, historical data, data about chronology of positions of mountain glacier moraines, and data of synthesis of multi-proxy evidences of temperature changes in the past.

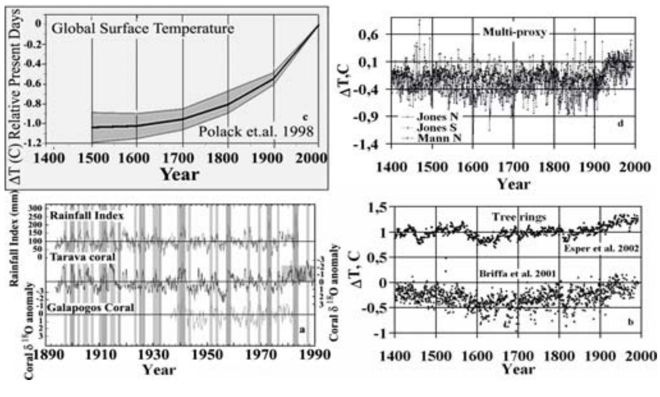

Figure 2 Reconstruction of paleoclimatic data: a [Cole et. al. 1993], b [Briffa et al., 2001, Esper et. al., 2002], c [Pollack et. al., 1998], d [Jones et.al., 2001, Mann et.al. 1998]

The reconstruction results of proxy paleoclimatic data (Fig. 2) show a discrepancy between some plotted data (dendrochronology, corals, geothermy). The distribution of paleoclimatic stations of geothermal, dendrochronological, glaciological and geochemical (coral) studies of the Earth's thermal history on the terrestrial globe has a pronounced regional character. This is the first weak point of the paleoclimatic method. Therefore, the global expansion of paleoclimatic tendencies one can consider only as the hypothesis requiring experimental verification. The second weak point is the necessity of calibration of the indirect paleoclimatic information. Here, the radiocarbon probing method plays an important role. The validity of dating is estimated using certain model of the past, which itself needs its validity estimation. Giving preference to certain model leads automatically to the corresponding uncertainty of radiocarbon dating. This means that radiocarbon dating is not an independent parameter. Further, paleoclimatic data calibration must be performed using the meteorological data of specific regions rather than their global characteristics. Also, it is necessary to take into consideration poor time resolution of paleoclimatic data.

2.3 Satellite technique

Satellite technique has been developed in projects "Nimbus", "TIROS", "NOAA", "GOES", "DMSP", "EOS", "Meteor" as well as in many others. In addition, observing satellite system consisting of low orbiting GPS satellite assembly, which measures temperature basing on delay and atmospheric transmittance of radio signals on frequencies of 10.3, 17.2, and 22.6 GHz.

The principal devices used for gathering satellite information on temperature relief structure of the Earth's surface and its atmosphere are the scanning radiometer AVHRR and the Microwave Sounding Units (MSU), placed on geostationary and polar orbiting satellites.

Advanced Very High Resolution Radiometer [Brown et. al., 1985] forms images of the Earth in 5 channels. MSU is a four channel scanner, measuring microwave radiation in the oxigen absorption band from 50.3 to 57.95 GHz.

Active remote sensing of the Earth's limb from GPS satellites enables one to calculate the atmosphere temperatures at high altitudes with small water vapor contents. Additional information for separation of the contributions of water vapor and temperature [Eriksson et. al., 2003] is necessary at low heights.

Spectral atmospheric transmission and spectral channels of devices AVHRR and MSU in the range 0.4-100000 microns are shown in Fig. 3a.

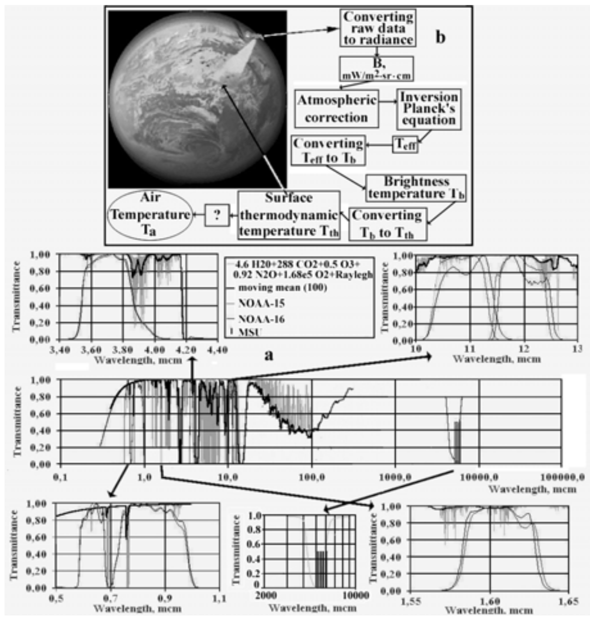

Figure 3. The spectral channels of devices AVHRR and MSU (a), and satellite information reduction procedure (b).

The routine procedure of reducing the AVHRR and MSU data into temperature (Fig. 3b) has evident sources of uncertainties.

Uncertainties in primary data reduction. The measurements in visual channels (1 and 2) are transformed in albedo values and thermal infrared channels (3, 4, and 5) into temperatures**.** Only the pre-launch calibration is used for the calibration of the visual channels as the corresponding onboard calibration source is lacking. The calibration of the AVHRR thermal infrared channels is performed before launch and during flight.

Uncertainties in the Earth's atmosphere accounting. The radiance values obtained in AVHRR channels 1 and 2 are corrected for Rayleigh scattering and ozone absorption. The correction of radiance values in the thermal range takes into account the radiation of the атмосферы, the Earth's surface and its repeatedly reflected descending atmospheric radiation.

The account of radiation components, especially for slant paths, depends on the appropriateness of the atmospheric models, used for corrections. According to the radiosonde data, there is a relationship between near-surface water vapor partial pressure and Earth's surface temperature (Fig. 4).

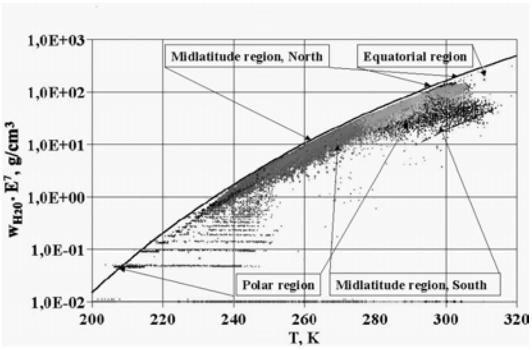

Figure 4. The dependence of near-surface water vapor partial pressure on Earth's surface temperature. Stations: 80 ^{o} N - 01004, 21504, 71072; 40 ^{o}N - 16560, 47058, 72597; 0^o - 64910, 91925, 96481; 40^{o}S - 68906, 91925, 94821; 80 ^{o}S - 89009, 89055, 89606.

The dependence has been plotted according to the data of 15 stations, measured for the period from 1990 to 2001 [Oolman, 2005]. The enveloping curve corresponds to the dependence of sated water vapor partial pressure dependence on temperature. The large data scattering show well the necessity of using correct atmospheric structural models.

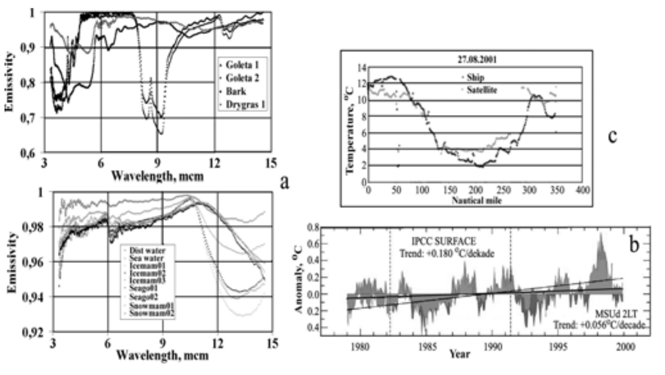

Figure 5. The comparison of satellite and ground temperature measurements [Christy et. al., 2000, Bukin, 2001], and the emissivities of different materials.

Uncertainties in the transformation of corrected radiance into brightness temperature. The data transformation is performed in three steps. First, the integrated radiance values obtained in the thermal infrared channels are transformed into effective brightness temperatures according to Planck's law. The two latter radiation sources in the infrared region are strongly dependent on the surface emissivity. Second, the effective temperatures are transformed into brightness temperatures, which are transformed for the materials with known surface emissivity values (Fig. 5b [Zhang, 1999]) into the thermodynamic temperatures of the surface.

Uncertainties in the conversion of the thermodynamic temperatures into surface temperatures. This is the most complicated and controversial transformation, being based on theoretical models. The transformation is often performed using ordinary adiabatic approximation. The results of the temperature measurements made measurements are shown in fig. 5b and 5c.

2.4 Earth's global albedo measurement technique based on earthshine.

Ten years ago, it was proposed [MacDonald and Koonin, 1992.] to combine earthshine ground measurements with satellite data. The results of Earth's global albedo determination through earthshine observations are given in Table 2. The data show decrease of the albedo during the last five years and then its subsequent increase.

Table 2 Annual mean albedo values [Palle, 2003]

Year	Mean albedo	St. Err. Mean	% error	Nights
1994	0.316	0.005	1.6	44
1995	0.319	0.007	2.2	29
1999	0.297	0.003	1.0	117
2000	0.310	0.003	1.1	105
2001	0.306	0.003	1.1	89
1994/1995	0.316	0.004	1.4	73
1999/2001	0.301	0.002	0.6	311

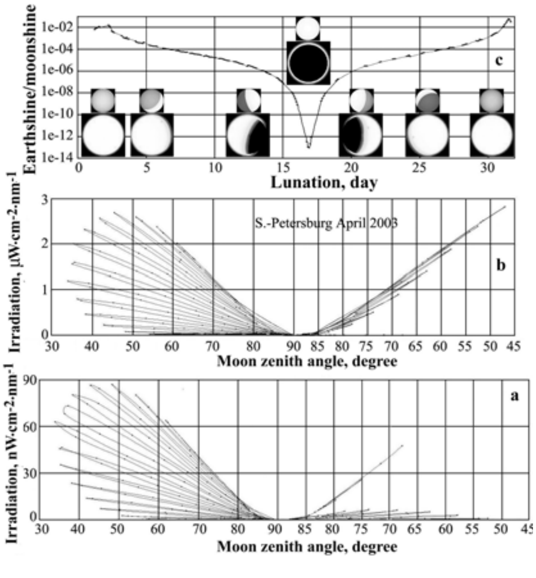

Figure 6. The Earth's irradiation by bright part (a) and the dark part (b) of moon's disk, and ratio (c) of Earth's irradiation with the Moon, irradiated by the Sun and the Earth at a wavelength of 550 nm for lunation in April 2003.

The variations of Earth's irradiation by Moonshine at wavelength 550 nm with changing Moon's zenith angle and the calculation results of the ratio of Earth's irradiation with Moonshine caused by radiation of the Sun and the Earth are presented in Fig. 6 [Khokhlov, 2004]. The lobes in Fig. 6 show daily irradiation variations and their enveloping curve is describing lunar orbit hodograph during a lunation. The calculated image of the Moon and that of the Earth, which one could see from the lunar surface, are shown in the lower part of Fig. 6c. The data for various zenith angles fit into a smooth curve. The calculations of lunar surface radiance and irradiation of Earth's atmosphere at various heights by Moon show the complicated features of the variations. A part of them is determined by the irradiation of lunar surface and depends on phases of the Moon and the Earth. Short-period variations depend on Moon's zenith angle and Earth's atmosphere properties. The amplitude of variations and the position of variations maximum is defined by lunar orbit hodograph position. The calculation of Moon radiance has shown that the periods between 3…8 and 25…29 days of a lunation are the most favorable moments for Moonshine observations. In these cases one should choose the lunations with the minimal zenith angles of the Moon.

3. CONCLUSION

The common shortcoming of all the techniques is their coverage of not all the globe and difficulty of an account of daily variation.

Historical net. The results presented in Fig. 1 show the influence of meteorological stations distribution over the globe and strong dependence of characteristics of large-scale trends on average annual temperature determination method and the correct account of daily variations. Temperature must be measured not less than 4 times a day for the reliable reproduction of trends at the regions with pronounced daily variations.

Paleoclimate. Paleo data interpretation and their calibration on historic data are based upon important assumptions [Mann, 1998], a part of which has its own limitations and, strictly speaking, does not prove the historic data.

Satellites. The atmospheric correction of the satellite data in visual and near infrared range does not take into account the effects of water vapor and aerosols. Moreover, even when these effects are taken into account, considerable differences can be observed due to application of different programs, which use big aerosol optical thicknesses and zenith angles of more than 60 degrees for inclined path calculations. The spectral dependence of radiance and emissivity can cause essential change of the final thermodynamic temperature, whose recalculation into the air temperature is very problematic. As satellite instruments are developed for daily weather forecast, they are not calibrated with the accuracy that is necessary for climate study.

Earthshine. In spite of complexity of interpretation of Earthshine measurements, this inexpensive technique of climate global change investigations is promising.

4. ACKNOWLEDGEMENTS

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